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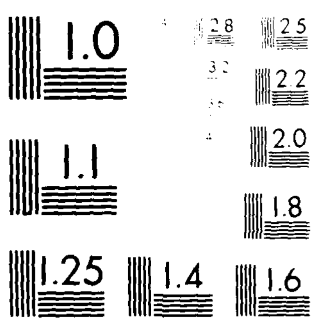

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DRY LAKE VALLEY, NEVADA

Prepared for:

U.S. Department of the Air Force
Ballistic Missile Office
Norton Air Force Base, California 92409

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Results of aquifer ~~testing~~ of the valley-fill aquifer ~~in~~ Dry Lake Valley, Nevada gave (in the [illegible]) a drawdown of 44.8 feet after 239 hours of pumping at a discharge of 500 gallon per minute. The Theis recovery method gave a transmissivity of 5200 ft2/day for the shallow aquifer and 6500 ft2/day for the deeper aquifer

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FOREWORD

This report was prepared for the U.S. Department of the Air Force, Ballistic Missile Office, in compliance with Contract No. F04704-80-C-0006. It presents the results of numerical modeling of the alluvial ground-water system of Dry Lake Valley, Nevada. Ground-water system models of this type were to be used in conjuction with results from exploratory drilling and aquifer testing as input for development of final water management plans for all proposed MX deployment valleys in Nevada and Utah. Subsequent to the President's decision to cancel plans for MPS basing of the MX missile system in Nevada and Utah, it was decided to prepare this report to document the modeling approach that was being utilized.

The initial sections of this report describe the physical hydrology of Dry Lake Valley and the development and calibration of the numerical model. The remaining sections of the report describe results of simulating MX water withdrawals from the valley-fill aquifer system.

TABLE OF CONTENTS

LIST OF FIGURES

TABLE OF CONTENTS (con't)

LIST OF TABLES

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1.0 INTRODUCTION

Exploratory drilling and aquifer testing was performed in Dry Lake Valley as part of the MX Water Resources Program. The objectives of drilling and testing were to obtain subsurface geologic information and to estimate the hydraulic characteristics of the valley-fill aquifer.

As part of the 1980 MX Water Resources Program, an exploratory well in excess of 500 feet (152 m) deep was scheduled to be drilled in Dry Lake Valley. The process of selecting the drilling site in the valley involved consideration of the following criteria: 1) hydrogeologically favorable areas; 2) the lack of comprehensive hydrogeologic data; and 3) acceptable access and other conditions favorable for efficient drilling operations.

The favorable hydrogeologic areas were considered to be where the stratigraphic layering of fine-grained and coarse-grained deposits were expected. These areas were generally near the base of the alluvial fans extending outward into the valley from the mountain front. These potential siting areas were refined to include only those areas having little or no existing hydrogeologic data. The great depth to ground water in Dry Lake Valley (in excess of 300 feet [91 m]) required that a deep exploratory well (in excess of 500 feet [152 m]) be drilled to adequately test the valley-fill aquifer.

The hydrogeologically acceptable sites were further refined to areas with accessible roads capable of carrying heavy drilling

equipment. In addition, the final sites were chosen as near as possible to a source of water for drilling. The selected location for exploratory drilling and aquifer testing in Dry Lake Valley was T3S/R64E-12ac at an elevation of 4645 feet (1416 m) above mean sea level (Figure 1). Drilling, and subsequent testing, at this site began on 3 January 1980.

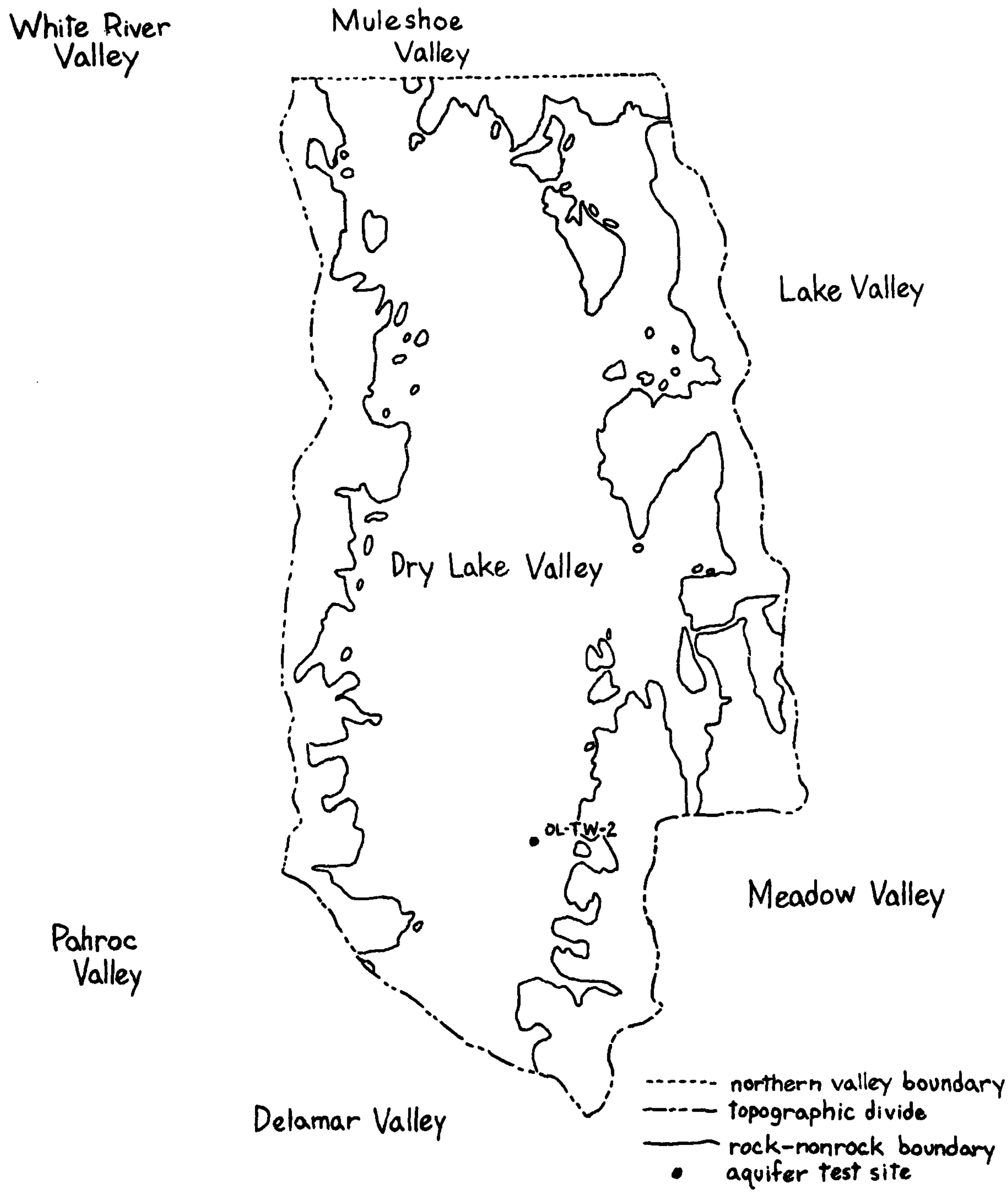

Figure 1. Location map Dry Lake Valley, NV, valley-fill aquifer test site.

2.0 TEST DRILLING AND WELL CONSTRUCTION

2.1 METHOD

Two borings were drilled at the test site in Dry Lake Valley and ultimately completed as a test well an' a multiple piezometer observation well. Drill cuttings were collected and logged at 10-foot (3-m) intervals. Geophysical borehole logs were made after the drilling of each hole.

Drilling of the borehole for the observation well began on 13 January 1980. A bucket auger was used to install a 22-inch (56-cm) diameter temporary surface casing to a depth of 40 feet (12 m). Reverse rotary drilling was used to make an 18 5/8-inch (47.3-cm) diameter hole below this depth. The boring was completed at 1305 feet (398 m) below land surface in poorly sorted gravel with about 25 percent sand.

The drilling of the borehole for the test well began on 26 January 1980, 475 feet (145 m) from the first boring. The procedure used in drilling the boring was similar to that used for drilling the borehole for the observation well. A 22-inch (56-cm) surface casing was installed to a depth of 40 feet (12 m) below land surface. Reverse rotary drilling was used to make an 18 5/8-inch (47.3-cm) diameter boring. Drilling was completed at 1010 feet (308 m) below land surface in poorly sorted gravel and cobble.

2.2 LITHOLOGY

Drill cuttings and geophysical logs of the two borings indicate that the lithology is generally poorly sorted to well sorted

gravel with less than 30 percent sand. Traces of silt and clay were identified in the cuttings obtained from the observation well boring. These materials were not identified in the test well. Well-sorted gravel with less than five percent sand was identified between 690 to 730 feet (210 to 223 m) and 900 to 950 feet (274 to 289 m) below land surface in the test well boring. These intervals have been identified as potentially having the highest productivity. No confining layers were identified from the logs of either boring. The saturated thickness of the aquifer was estimated to extend from about 400 feet (122 m) below land surface to at least 1305 feet (398 m), the total depth of the observation well. Based on the lithology, the transmissivity of the valley fill was estimated to range from low (2000 ft^2/day [186 m^2/day]) to moderate (7000 ft^2/day [650 m^2/day]).

2.3 CONSTRUCTION

The construction of both the test and observation wells was based on the lithology of the valley fill as estimated from the drill cuttings and the geophysical logs. The test well was completed with 10-inch (25-cm) inside diameter steel casing. Screen was set in 20-foot (6-m) intervals from 600 to 620 feet (183 to 189 m), 650 to 670 feet (198 to 204 m), 700 to 720 feet (213 to 220 m), 750 to 770 feet (229 to 235 m), 800 to 820 feet (243.8 to 249.9 m), 850 to 870 feet (259.1 to 265.2 m), 900 to 920 feet (274.3 to 280.4 m), and 950 to 970 feet (289.6 to 295.7 m) below land surface corresponding to the most permeable sediments as determined from the geologic and geophysical

logs. The well screen used was a Johnson 10-inch (25-cm) inside diameter, wire-wrapped, steel screen with 0.060-inch (0.15-cm) openings. The screen size was designed along with the selected grading of the sand pack based on the grain size of the sediments. All casing and screen contacts were welded together. Before the casing was installed, the boring was backfilled to 1000 feet (305 m) below land surface. Once the casing (with screens) was set, the annular space was filled to 400 feet (122 m) below land surface with .092- to .056-inch (0.23- to 0.14-cm) graded sand pack. The remaining portion of the annulus was filled with pea gravel to within 10 feet (3 m) of land surface. Construction was completed with the placement of a cement seal to land surface. Immediately after construction, the test well was developed using swabbing and bailing techniques for 34 hours and surging for 12 hours.

The observation well was constructed with two 2-inch (6-cm) inside diameter steel piezometers to obtain water-level data at different depths during aquifer testing. These data will allow the estimating of aquifer properties and an assessment of the vertical conductivity of the valley-fill sediments. The deep piezometer was completed at a depth of 1300 feet (396 m) with a slotted interval between 1270 and 1290 feet (387 and 393 m) below land surface. Prior to installing the deep piezometer, the borehole was backfilled to 1300 feet (396 m) with .092 to .056 inch (0.23 to 0.14 cm) graded sand. After the deep piezometer was set within the boring, the annulus was filled to a depth of 1230 feet (375 m) with the graded sand and to 805

feet (245 m) below land surface with pea gravel. A 10-foot-(3-m-) thick cement seal was placed above this level, and the shallow piezometer was set. The shallow piezometer was completed to a depth of 795 feet (242 m). The piezometer consisted of a 2-inch (6-cm) steel casing with a perforated interval between 765 and 785 feet (233 and 239 m) below land surface. The annular space was filled to a depth of 750 feet (229 m) with the designated 0.092- to 0.056-inch (0.23- to 0.14-cm) graded sand pack. The remaining portion of the annulus was filled with pea gravel to within 10 feet (3 m) of the land surface. The observation well was completed with a 10-foot (3-m) cement seal. Both piezometers were developed by air-lift pumping for 19 hours.

3.0 AQUIFER TESTING

3.1 METHOD

The design of the aquifer test in Dry Lake Valley was based largely on a preliminary estimate of the transmissivity of the valley fill. This estimate was determined from the description of the lithology obtained from both the geologic and geophysical logs for the first boring at the test site. The aquifer test design included one test (pumping) well and one observation well. The observation well was completed with both a deep and shallow piezometer. The test well was designed to be pumped at a constant discharge, as determined from a step-drawdown test, for a duration of 10 days. Water levels in both the piezometers and the test well were to be monitored before, during, and after the pumping period.

Water levels in the test well and the piezometers were measured using a Sinco electric piezometer recorder with four pressure transducers. An electric sounder was also used frequently to measure water levels as a verification procedure against the measurements made using the Sinco unit. The pressure transducers were installed to obtain static water-level measurements prior to the beginning of the step-drawdown test. One pressure transducer was placed below the water table in each piezometer and in the test well. The fourth piezometer was placed just above the static water level in the shallow piezometer to measure changes in barometric pressure. Water-level measurements were made at one- to 30-minute intervals for four hours

during the step-drawdown and constant discharge tests and then expanded to one-hour intervals. Barometric pressure measurements were also made at each of these time increments.

3.2 OBSERVATIONS

Between 3 April and 27 April 1980, a step-drawdown and a constant discharge aquifer test were conducted at the site. The pump installed in the test well was a Peerless 23, stage vertical line shaft turbine pump, closed impeller type with 8-inch (20-cm) bowls. The pump was set at 584 feet (178 m) below land surface. The discharge rate was controlled by a gate valve and monitored with a 6-inch (15-cm) diameter totalizer.

The step-drawdown test was conducted on 3 April 1980. Prior to the test, the static water level in the test well was recorded at 396.1 feet (132 m) below land surface. The test consisted of four separate discharge rates ranging from 300 to 740 gpm (19 to 47 l/s) in which each rate was maintained for 120 minutes (two hours). From the discharge and drawdown data, the specific capacity of the well was determined (Table 1).

Specific capacity versus drawdown and discharge versus drawdown were plotted to determine the optimum pumping rate. Figure 2 indicates that a discharge rate in excess of 735 gpm (46 l/s) should be used for the aquifer test. In addition, the increase in the specific capacity is an indication that the test well was not fully developed. Because of the limitations of the pump and well design, a discharge rate of 735 gpm (46 l/s) was selected for the continuous discharge test.

Table 1: Step-Drawdown Test Summary

Discharge Rate (gpm)[1]	Duration (Minutes)	Drawdown (feet)	Specific Capacity (gpm/ft dd)[2]
300	120	26.6	11.3
430	120	36.7	11.7
500	120	47.8	10.5
740	120	58.2	12.7

Notes:

1 Gallons per minute

2 Gallons per minute per foot of drawdown

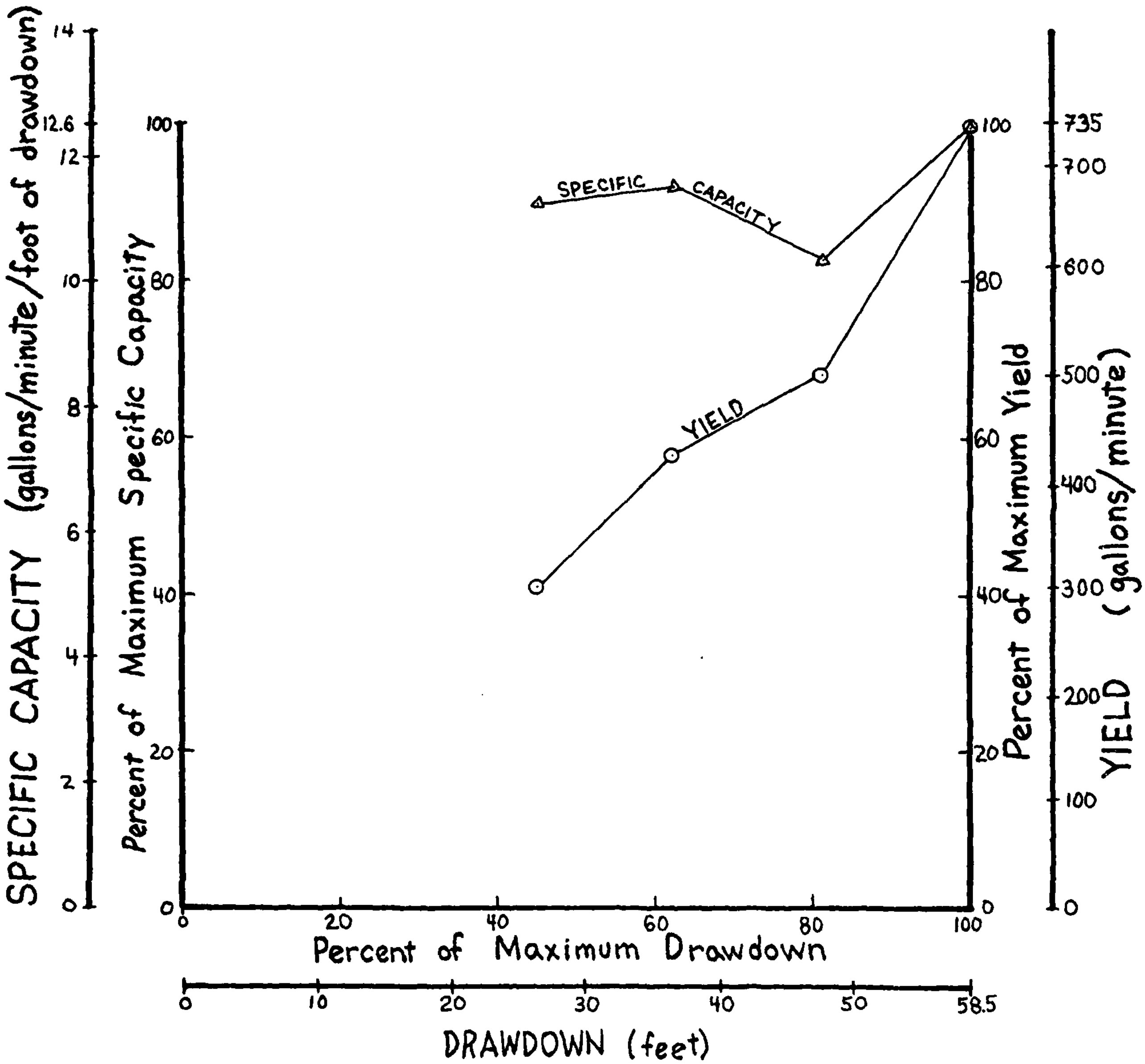

Figure 2. Specific capacity and yield during step-drawdown test.

The constant discharge aquifer test began on 10 April 1980. Prior to the test, the water level in the test well was measured at 396 feet (120 m) below land surface and 385 feet (118 m) below land surface, 475 feet (145 m) away in both the shallow and deep piezometers. During the test, water levels were measured and recorded along with the time each measurement was made in the test well and both piezometers. Immediately upon termination of pumping, recovery data were collected until water levels returned to near prepumping levels. The time increment for the collection of recovery data was similar to that utilized during the pumping period with a short time increment in the early portion and later expanded to one hour. Recovery data were collected for 155 hours (about 6.5 days).

4.0 AQUIFER TEST ANALYSES

4.1 AQUIFER PROPERTIES

The drawdown and recovery data for both the test well and the observation well were analyzed to determine the aquifer properties of transmissivity and storativity. The storativity has been defined as a general term referring to either or both the coefficient of storage or the specific yield of the aquifer. The coefficient of storage refers to the volume of water the aquifer releases from or takes into storage as a response to a change in head, attributed to the compressibility of the aquifer material and water. In water-table aquifers, the water released from or taken into storage in response to a change in head is attributed largely to gravity drainage (delayed drainage) and is referred to as the specific yield of the aquifer. The volume of water released or taken into storage attributed to the compressibility of the aquifer materials and water is very small compared to the specific yield and can only be detected immediately after a change in head occurs, before gravity drainage effects can be realized.

Several important considerations were necessary to determine which set or combination of methods should be utilized to provide the most reliable estimate of the aquifer properties. In principle, any of the aforementioned data sets could be analyzed by any of several potentially applicable methods to determine the property estimates. However, these estimates could have varying degrees of reliability depending on the assumptions of the method of analysis and quality of the data.

4.2 DRAWDOWN AND RECOVERY DATA ANALYSIS

The factors that effect the reliability of these estimates are discussed in the following paragraphs, and a hierarchy of methods and appropriate data is developed for the analyses of the drawdown and recovery data collected from the test and observation wells.

Dry Lake Valley, like other alluvial valleys of the Basin and Range province in Nevada and Utah, is generally characterized as thick (generally in excess of 500 feet [160 m]) and moderately permeable (clay, fine to coarse sand, and gravel). The aquifer test in Dry Lake Valley was designed to penetrate and stress a high percentage of this saturated thickness. The observation well, through multiple piezometers, was designed to measure the response over a large portion of the saturated thickness. The aquifer test designed for these media can, therefore, be characterized by three major features.

The first feature is that the thick, moderately permeable, water-table aquifers respond to pumping with delayed yield of water that is released from storage by the declining water levels around the well. The effect of the delayed yield is to produce an initial response at small elapsed time from the beginning of the pumping stress that is indicative of only the compressible storage of the aquifer, both that of the ground water and the aquifer matrix material. At large elapsed time, the gravity drainage of water from the aquifer material produces a response that is typical of the normal specific yield of a

water-table aquifer. The intermediate response is a transition from just the compressible and gravity drainage yields. This intermediate period of response is, by itself, similar to the response that is indicative of a recharge boundary effect. However, analysis by such an assumption would be totally erroneous in terms of long-term response. The magnitude of the delay in the specific yield response can be shown to decrease monotonically with 1/r (r, being the distance from the pumped well to the observation well).

The second feature of the aquifer test is that effects of partial penetration exist and are most noticeable, again, at small radial distances from the pumped test well. The pumped well was designed to stress a large portion of the saturated thickness to minimize these effects. The observation well was designed to provide a measure of the disparity in shallow and deep responses to indicate the existence or absence of partial penetration.

The third factor that influences the reliability of the aquifer test results is the degree of well development and the efficiency of the well design. Unfortunately, the degree of well development and the efficiency of the combined screening and packing is difficult to assess quantitatively.

As a result of these considerations, the following approach was developed in the design and analyses of the Dry Lake Valley aquifer test. The data collected from the test well during both the drawdown and recovery test allowed only an approximation of

transmissivity and no estimates of storativity. The observation well was located 475 feet (145 m) from the test well in an attempt to obtain data on the delayed drainage effects of the valley-fill aquifer. The distance to the observation well cannot be too large since the time for the drainage effects to become apparent increases in proportion to r^2. Finally, the drawdown data are preferred to recovery data for analyses because delayed yield and the resultant hysteresis of the quasi-reversible process adversely affect the recovery data in either the test or observation well. Therefore, the hierarchy of the data analysis is:

1. Observation well drawdown data to produce estimates of:
    a. transmissivity;
    b. effective compressible storage;
    c. specific yield (with long-term response);
2. Test well drawdown data to provide a supporting estimate of transmissivity;
3. Observation well recovery data to provide a supporting estimate of transmissivity;
4. Test well recovery data to provide a supporting estimate of transmissivity.

The methods of analysis that were used for the Dry Lake Valley aquifer test are described briefly below.

4.2.1 Observation Well

The drawdown data for the observation well were plotted on four- or five-cycle semilog paper as a function of the log of elapsed time. The delayed yield phenomenon is characterized by four stages of response. The first stage is at very early elapsed time as the drawdown deviates from zero (Figure 3). The second

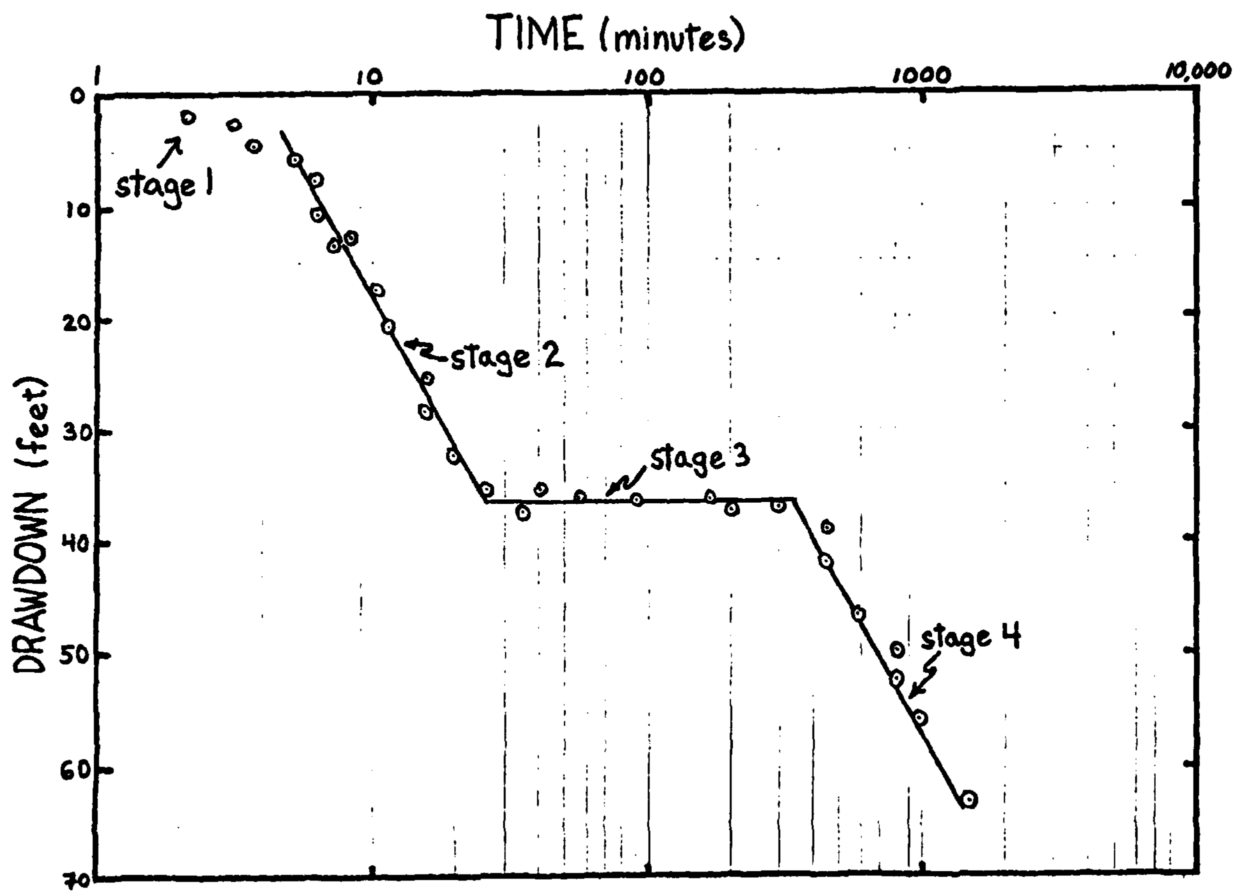

Figure 3. Hypothetical graph of drawdown vs. time indicating delayed yield effects.

stage is the compressible storage effect in which the drawdown increases nearly linearly with logarithmic time, approximately in the straight-line fashion, indicating Theis-type (nonequilibrium) response. However, the nondimensional u, of the W(u) function

$$W(u) = \frac{e^{-u}}{u} \, du$$

$$s = \frac{Q}{4 \quad t} \; W(u)$$

Where: $u = \frac{r^2 S}{4Tt}$

s = drawdown (feet)

r = distance to the observation well (feet)

Q = discharge (ft^3/day)

t = time (days)

T = transmissivity (ft^2/day)

S = storativity (coefficient of storage for confined aquifers)

was greater than 0.01. u must be less than 0.01 for the validation of the Jacob semilog straightline analysis (Jacob, 1946). The third segment of the delayed yield response is characterized by a relatively horizontal line as the transition between compressible storage and combined compressible and specific yield effects progress. The fourth segment is again a nearly linear relationship with log time, as the full effect of specific yield is present in the response indicating a large time Theis-type response. The fourth segment was not present in the analysis of the Dry Lake aquifer test data.

A modified version of the method described by Neuman (1976) was used to analyze the drawdown data from the observation well. The modified Neuman procedure refers to a computer simulation incorporating both the semilog graph of drawdown versus time (Jacob, 1946) and Theis (1935) well function. The analysis of the semilog graph commences with the calculation of transmissivity and effective compressible storage coefficient from the nearly straightline segment of the second stage of response. The calculations are accomplished by a higher-order approximation to the W(u) function than the Jacob method of analysis. The higher-order approximation is formulated to be less than 0.03 percent error for all values of u less than or equal to 1.0, which allows two orders of magnitude increase in the range of appropriate analyses. The approximation is utilized to analyze the end points of the second segment of response to produce estimates of transmissivity and effective compressible storage, provided these points lie on a Theis curve without significant departure (this is checked utilizing a log-log graph of drawdown versus time (Figure 4). Figures 5 and 6 indicate where the log plot of drawdown versus time data for both the shallow and deep piezometers depart from the Theis type curve.

The fourth segment, if present, is analyzed as the second segment to produce estimates of transmissivity and specific yield. The transmissivity estimate should be comparable to that produced by the second segment. In the absence of the fourth segment of the delayed yield response, the final (end) point of the third segment was analyzed to estimate a lower bound of the

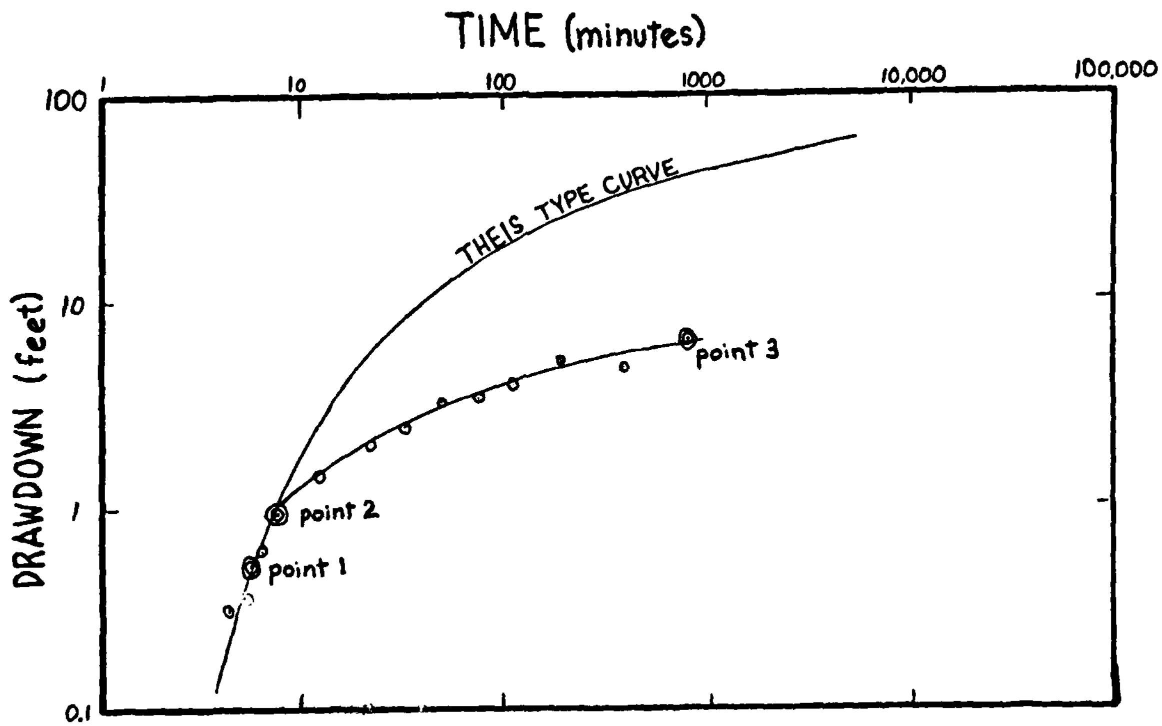

Figure 4. Log-log graph of drawdown vs. time for hypothetical test.

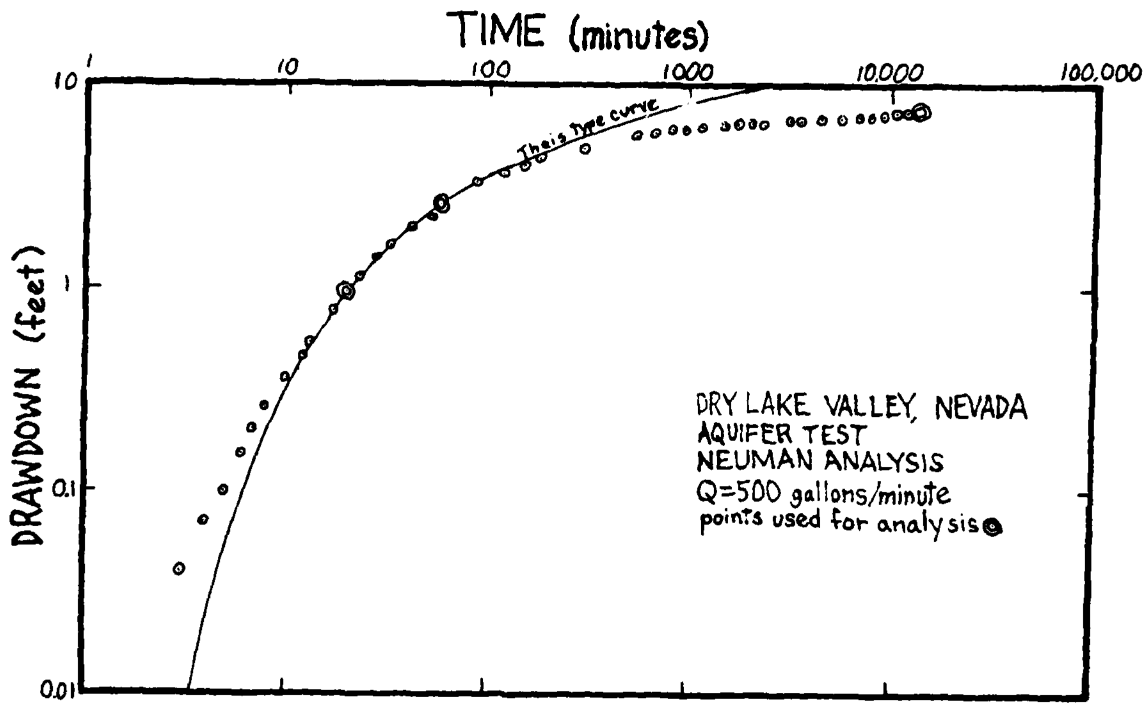

Figure 5. Log-log graph of drawdown vs. time for shallow piezometer.

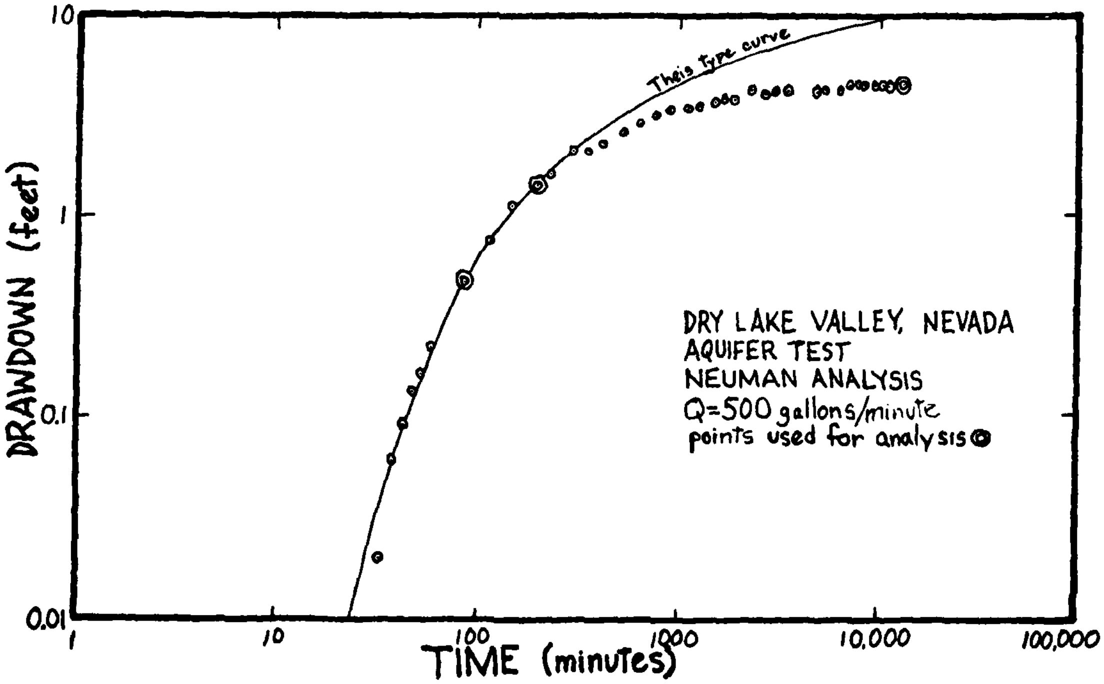

Figure 6. Log-log graph of drawdown vs. time for deep piezometer.

specific yield, assuming the transmissivity estimate of the second segment is correct (Figures 7 and 8). This method is a refinement of the method described by Neuman (1976).

4.2.2 Pumping Well

The drawdown of the pumped well was analyzed by the Jacob straightline method, utilizing the semilog plot, to estimate a transmissivity (Figure 9). This estimate is qualitative for all of the reasons discussed previously.

The recovery data for both piezometers in the observation well were analyzed using Theis recovery methods to estimate transmissivity (Figures 10 and 11). This estimate and the applicability of the method are qualitatively correct, again, for all the previously discussed reasons.

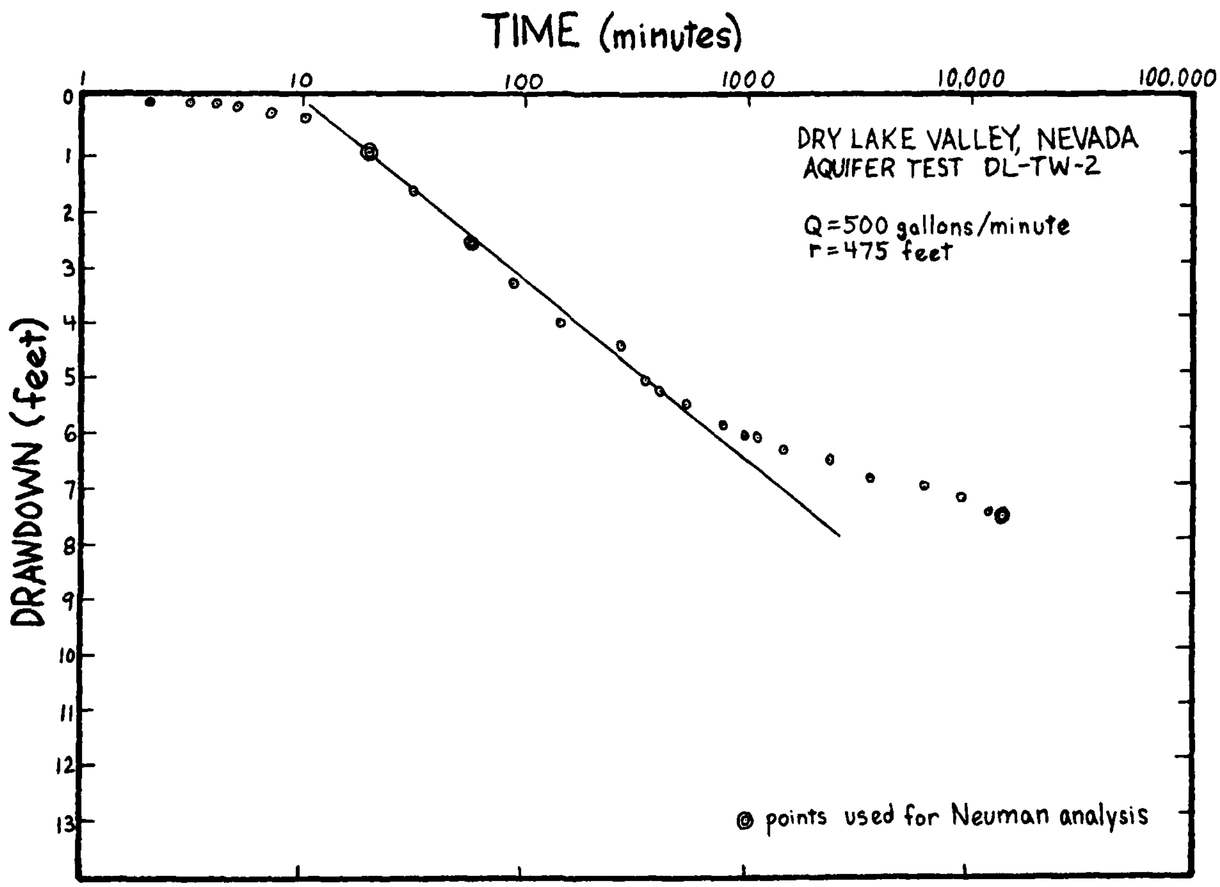

Figure 7. Semi-log graph of drawdown vs. time for shallow piezometer.

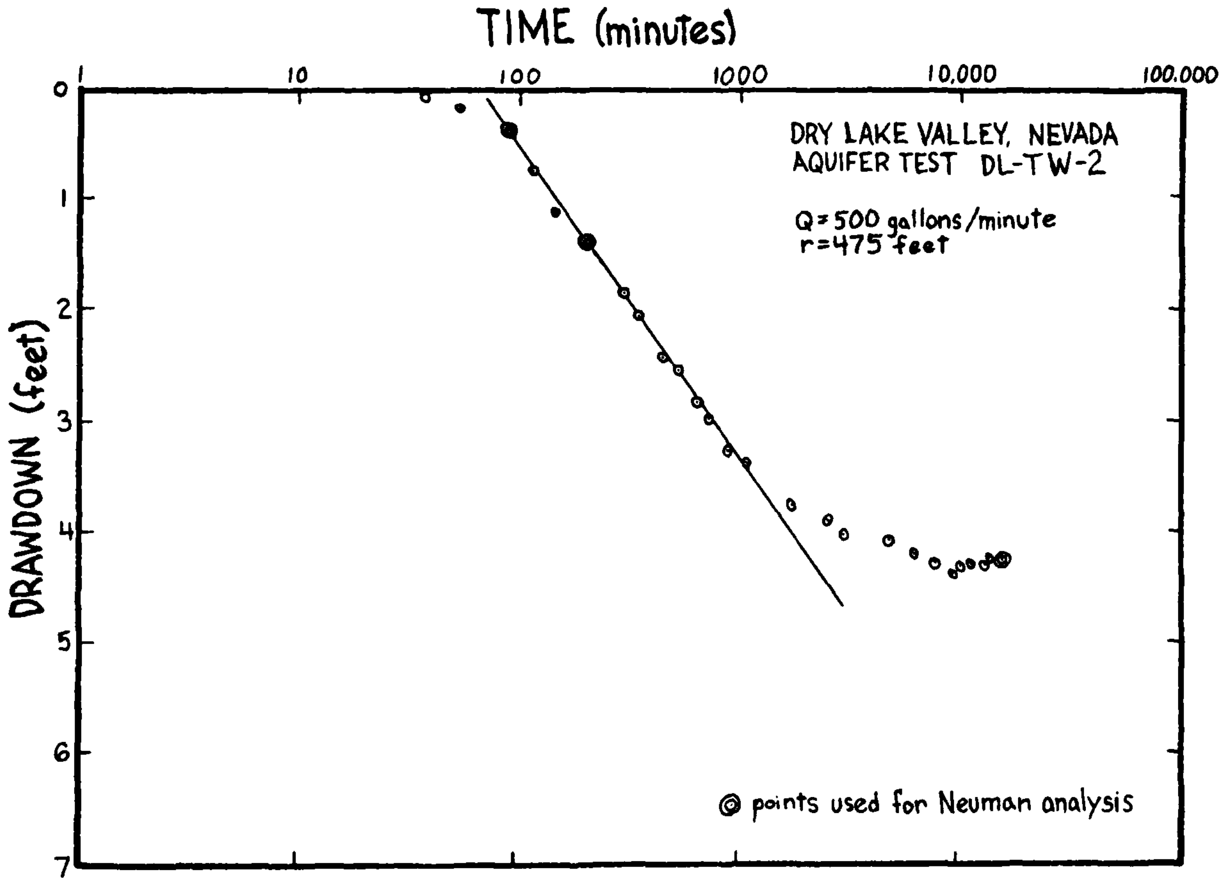

Figure 8. Semi-log graph of drawdown vs. time for deep piezometer.

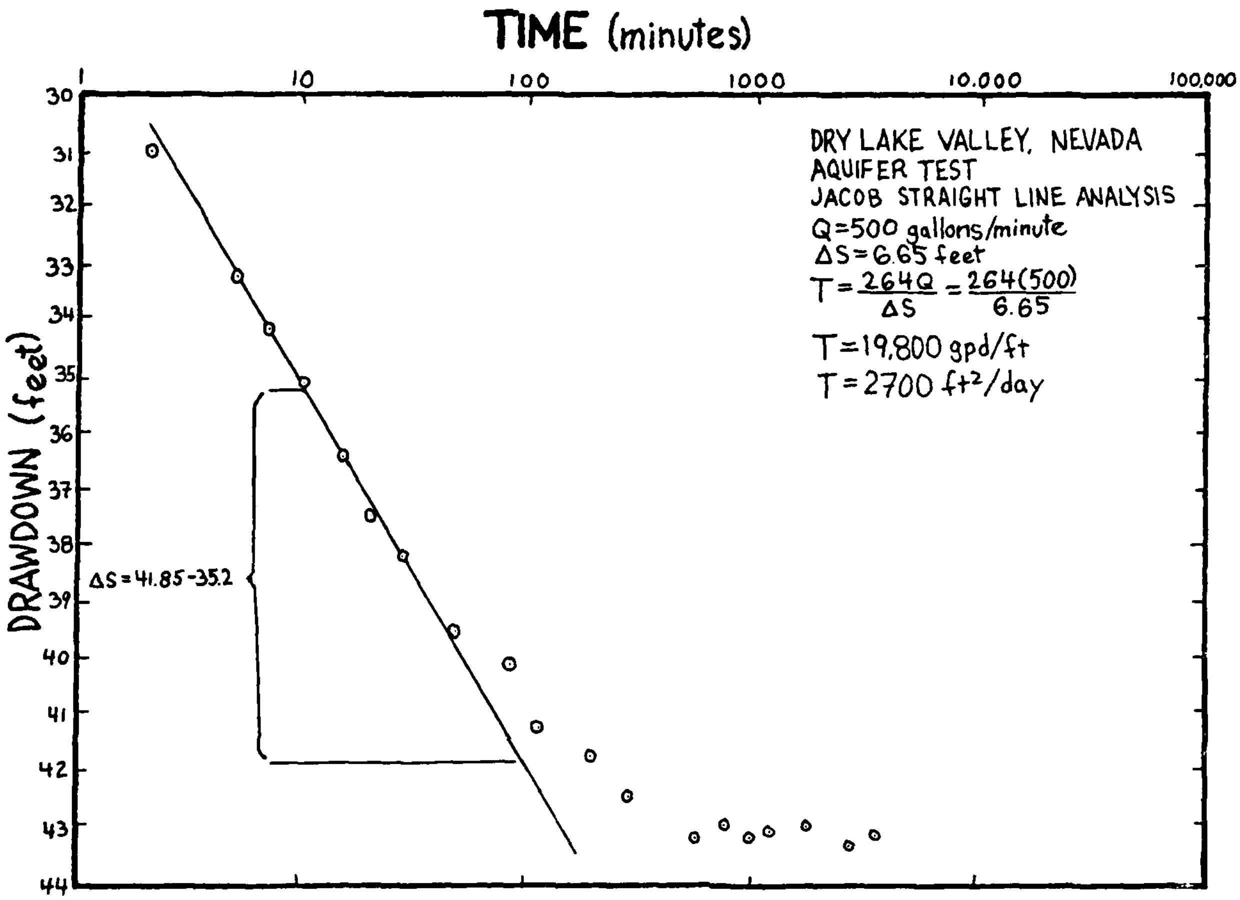

Figure 9. Semi-log graph of drawdown vs. time for test well.

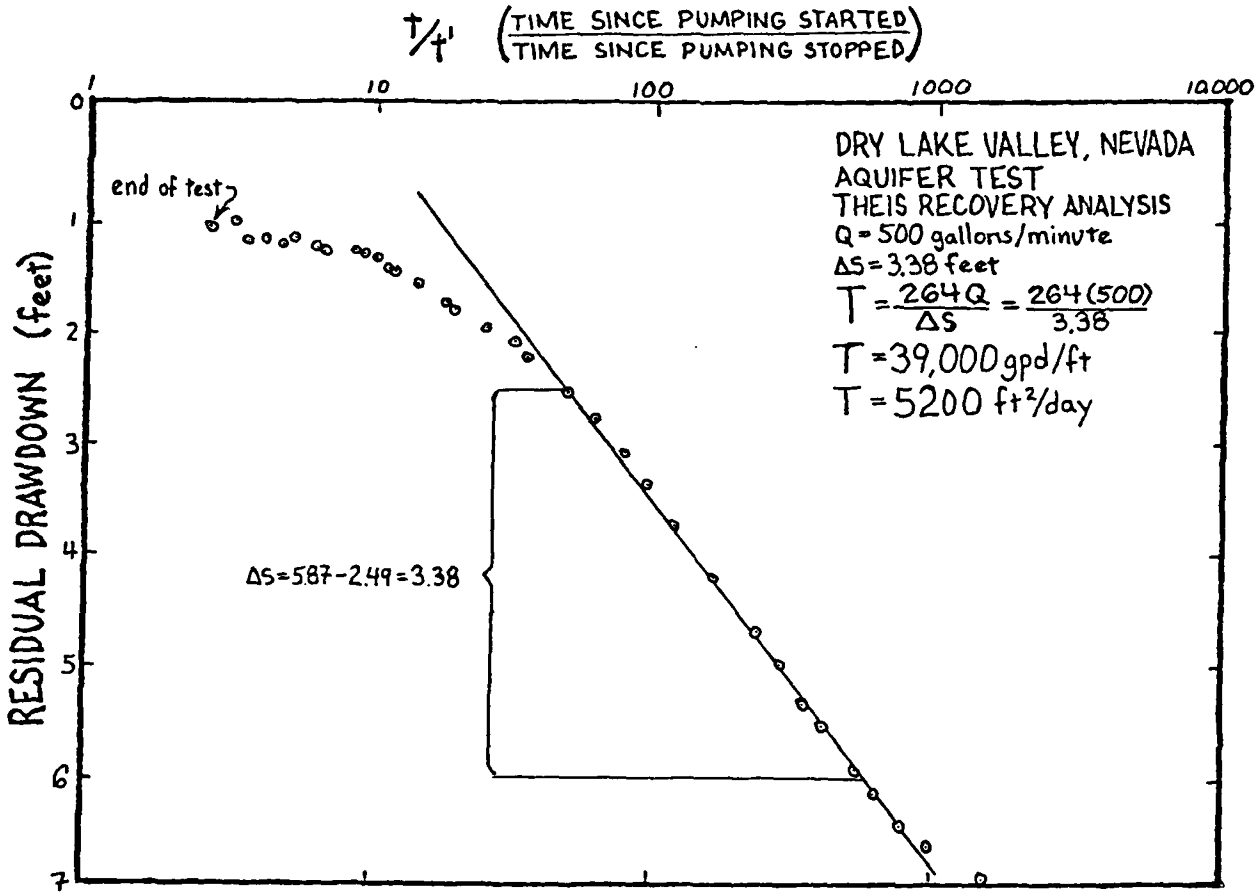

Figure 10. Semi-log graph of residual drawdown vs. t/t' for shallow piezometer.

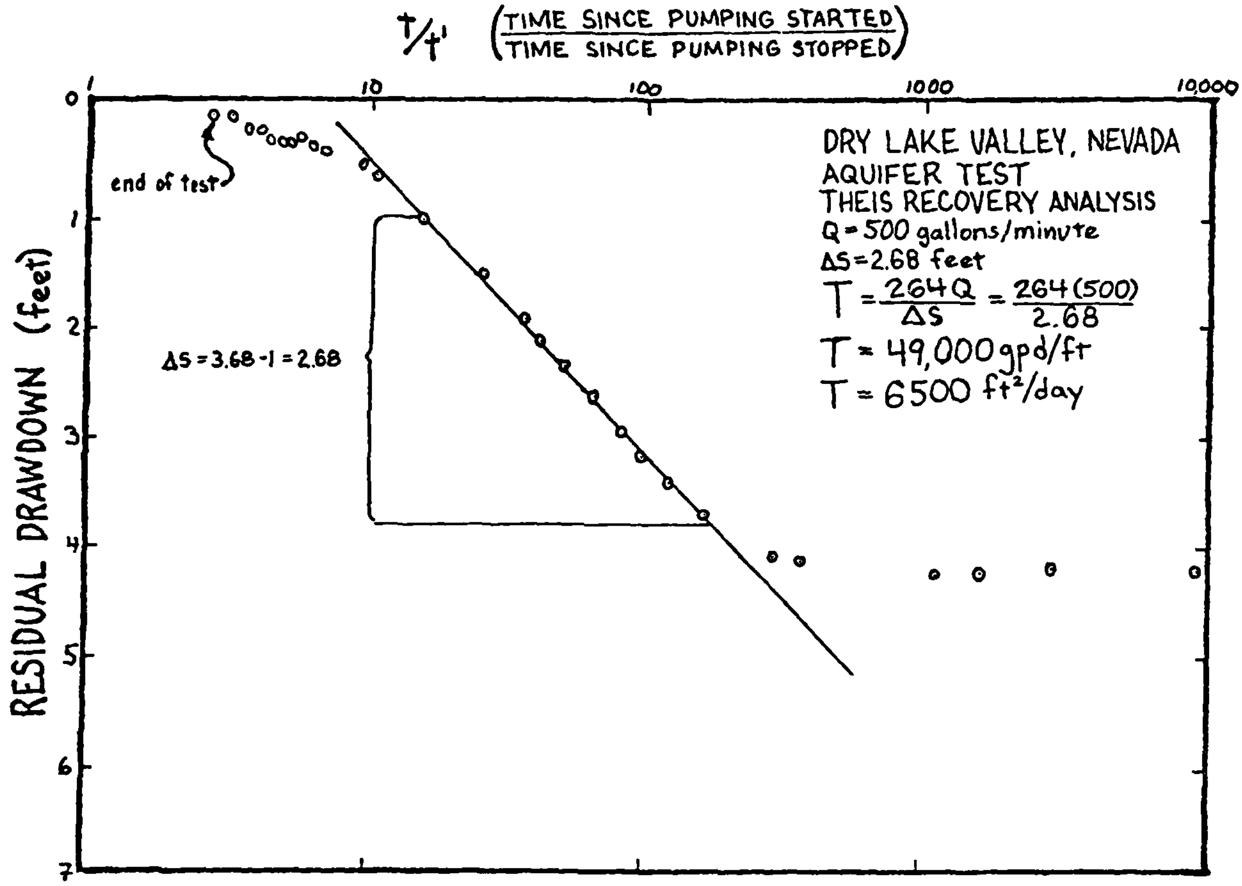

Figure 11. Semi-log graph of residual drawdown vs. t/t' for deep piezometer.

5.0 DISCUSSION

The results of the pumping and recovery portions of the constant discharge aquifer test were analyzed and estimates of the transmissivity, storage coefficient, and specific yield were obtained. The aquifer test was conducted for 239 hours at a discharge of 500 gpm, and a maximum drawdown at the test well of 44.8 feet (13.6 m) below land surface. Maximum drawdown in the observation well, 475 feet (145 m) away from the production well, was 7.5 feet (2.3 m) in the shallow piezometer and 4.4 feet (1.4 m) in the deep piezometer. The recovery test was monitored for 155 hours.

The Jacob (straightline) method was used to analyze aquifer test data from the test well (Jacob, 1946). The transmissivity was estimated to be 2700 ft^2/day (251 m^2/day). The modified Neuman method was used to analyze aquifer test data from the observation well. Using the second segment of the semilog graph of the drawdown versus time data, the compressible storage and transmissivity were estimated to be 5.3×10^{-4} and 3400 ft^2/day (316 m^2/day) for the shallow piezometer and 3.9×10^{-3} and 3700 ft^2/day (344 m^2/day) for the deep piezometer. However, the fourth segment of the data did not appear during the aquifer test. Thus, a minimum value for the specific yield was estimated using the last data point of the third segment of the data for each piezometer and the respective transmissivity values. The minimum value of specific yield was estimated to be 1.3×10^{-2} and 5.1×10^{-2} for the shallow and deep piezometers, respectively.

No estimates of vertical conductivity were made from the results of the Dry Lake Valley aquifer test. The Neuman methodology for the analysis of drawdown versus time data does have provisions for estimating the vertical hydraulic conductivity (Neuman, 1975). By knowing the transmissivity, an estimate of the saturated thickness, and B (usually determined from the type curves developed by Neuman [1975]), the vertical conductivity (K_z) can be determined using the following equation:

$$K_z = \frac{BTb}{r^2}$$

Where: B = independent dimensionless parameter

T = transmissivity (ft^2/day)

b = saturated thickness (feet)

r = distance to the observation well (feet)

However, the parameters needed for this calculation, the dimensionless B, and the saturated thickness of the aquifer, are not known.

The Theis recovery method was used to analyze recovery data from the observation well (Theis, 1935). The transmissivity was estimated to be 5200 ft^2/day (483 m^2/day) for the shallow piezometer and 6500 ft^2/day (604 m^2/day) for the deep piezometer. The analysis of the recovery data collected from the test well proved inconclusive.

The transmissivity value cited for Dry Lake Valley is 3400 ft^2/day (316 m^2/day), which was from data obtained from the shallow piezometer during the aquifer test. The data collected during the aquifer test from the observation well were preferred because of the hierarchy of data analyses which was discussed in the previous section. The estimated transmissivity and storativity of the shallow piezometer was used instead of the data from the deep piezometer because it was assumed that the shallow piezometer was developed more efficiently during air lifting. The storativity value used in this report is the lower bound of the specific yield, 1.3×10^{-2}, as estimated from data of the shallow piezometer.

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-8